Tests of MHATT-CAT's High Heat Load monochromator beam stability.

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Abstract

This report summarizes our test of the High Heat load Monochromator intensity stability in 7 ID-D in late February 2000, where beam motion is likely the worst due to the long lever arm distance from the mono. We also did some tests of the effect of the coolant pressure on the tilt of the first crystal in Mid March 2000 and found a huge effect of the pressure on the first crystal angle. Tilt of the first crystal theta angle as large as 425 μrad for a 30 PSI change occur. Since the cryocooler pressure oscillate by typically 0.3 PSI, this causes a beam motion at 30 m from the mono on the order of 240 μm. The magnitude of the beam motion measurements are consistent with this estimate, but the motion is in the opposite direction than expected from the pressure fluctuations.

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I. BACKGROUND

Over the last year of operation, it has been found by several MHATT-CAT users in 7 ID-C and D that the intensity of the monochromatic beam has large fluctuations. The total flux typically has fluctuations on the order of a few percent rms. Recently, Yizhak Yacobi tested the stability and found that the flux variations could be as large as 100 % when a vertical slit blocks half the beam. Given that the beam size used was 200 μm, this implies a beam motion of about 100 μm, 24 m from the monochromator, or about a two microradian angular change. Yizhak performed a similar test at PNC-CAT and found that the beam was much more stable on their beamline, especially when their feedback was turned on.

After discussing with Steve Heald from PNC, we were told that they feedback on the beam position. They use a split ion chamber to measure the beam position, and use a hardware PID controller to change the angle of their second crystal with a piezo actuator. They also made some serious mounting changes to their crystal manifold which they believe helped their beam stability. With the new manifold, their mono scans energy reproducibly. The BESSRC (sector 12) group also uses feedback but only feedback on the intensity. They are using a very similar crystal mount as we are. It thus seem that without any substantial engineering we could stabilize the output of our monochromator using simple feedback.

Before any changes are performed, we decided to quantify the intensity fluctuations and beam motion caused by our monochromator. The first part of this report will show quantitative time series analysis of the intensity fluctuations. We wanted to check whether the pressure fluctuations of the cooling liquid was causing the problem, so we also turned the cryocooler off. We also performed some test without X-rays with two tiltsensors to test how the pressure in the crystal coolant lines affect the tilt of the first crystal. Tiltsensors provide enough angular resolution to measure sub-microradians shift of the first crystal. Finally, we will include more experience learned during the early May 2000 realignment of the monochromator.

II. BEAM INTENSITY FLUCTUATIONS

FIGURES

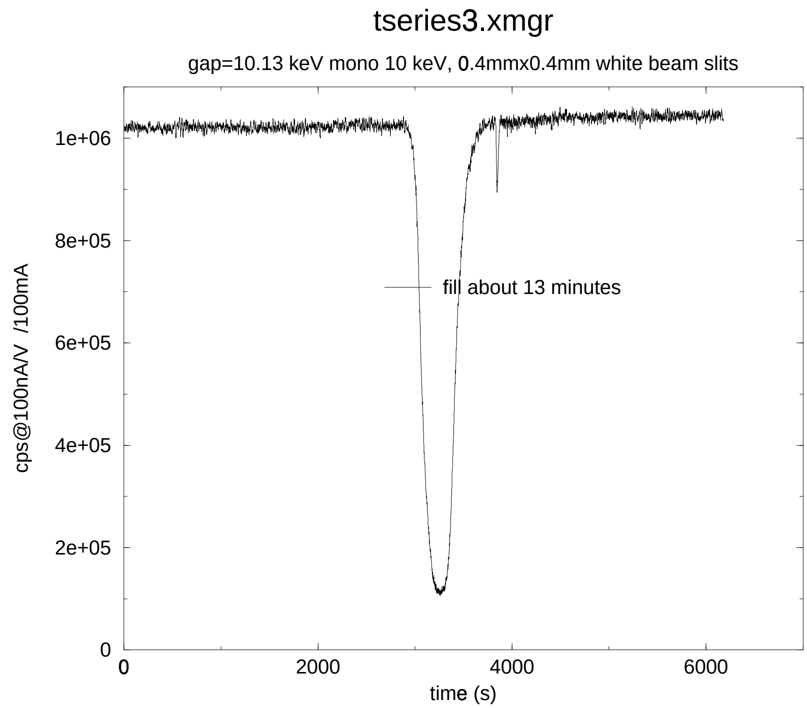

FIG. 1. Total flux variation before, during and after a LN2 Cryocooler fill.

We tested first the flux stability with the Monochromator set to diffract 10.0 keV X-rays, with an undulator set at 10.13 keV which optimized the total flux. The white beam slits were set to $0.4 \times 0.4\text{mm}^2$ for this test. In the beamline, the white beam slits are at 26.5 m, the monochromator at 30 m, and an experiment aperture in ID-C would be at 53 m. An aperture could be closed in 7-ID-D, placed 57.5 m from the source. Fig. 1 shows a time serie of the total flux measured with an ion chamber in air. The aperture was fully opened. We are all now familiar with the fact that the total flux is lost during a fill of the LN2 cryocooler. This fill typically last about 13 minutes. During the fill, warm gas from the LN2 feed line comes in the Dewar that houses the LN2 pump and reservoir, and disturbs the closed loop pressure by typically 2 PSI. Once liquid flows in the Dewar, the intensity comes back. Oxford is aware of this problem, and solutions have been proposed to fix this problem. The addition for example of a LN2 vacuum jacketed line from the Mezzanine feedline to the cryocooler is believed to reduce the amplitude of the fluctuations when filling occurs because it reduces the amount of warm gas flowing into the system. Figure 2 shows the Si (111) rocking curve at 10.0 keV near 77 K. The Darwin width (here the FWHM) is 6.0 arc seconds (29.2 μrad). Before and after the LN2 fill, the total flux is typically stable to within 0.7 %, which implies that the two crystals remain aligned to within a fraction of the Darwin width.

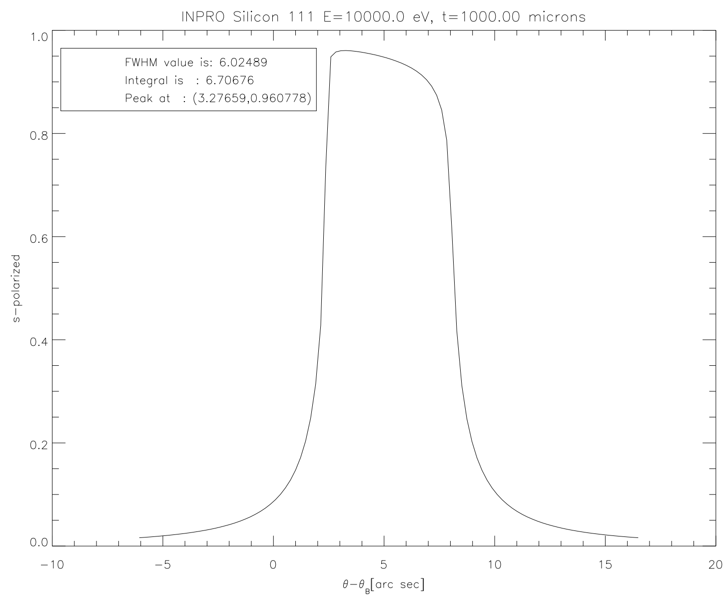

FIG. 2. Theoretical rocking curve of Si (111) at 10.0 keV.

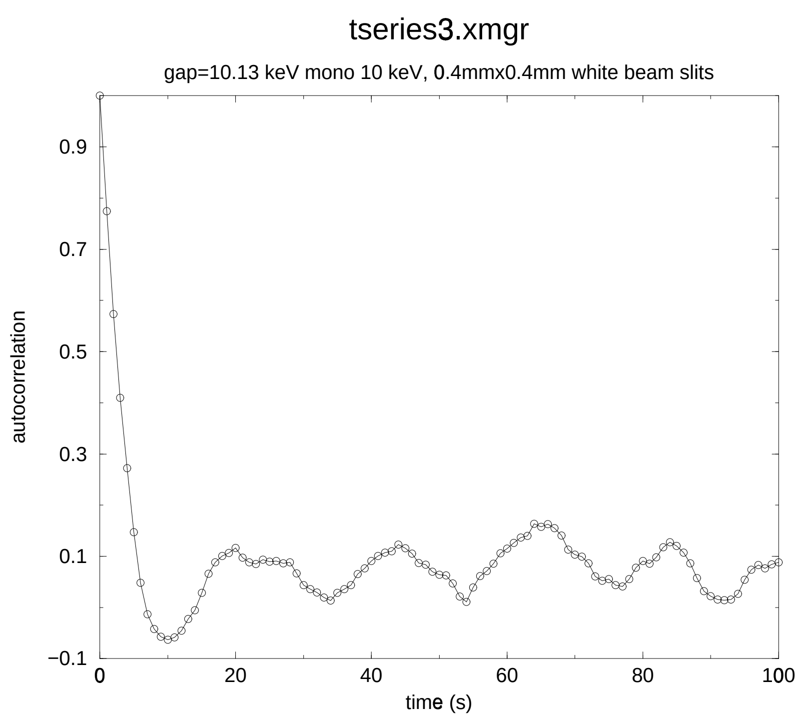

FIG. 3. Time correlation function of the total flux for the data before the LN2 fill in Fig. 1.

Fig. 3 shows the time correlation function of the total flux in Fig. 1. The figure shows a 7 sec long decay of the time correlation function, and oscillatory behavior with a 20 s time scale. We suspect that this 20 s time scale is due to pressure variations in the closed loop with 0.3 PSI amplitude, having a very sharp onset, and a slow relaxation.

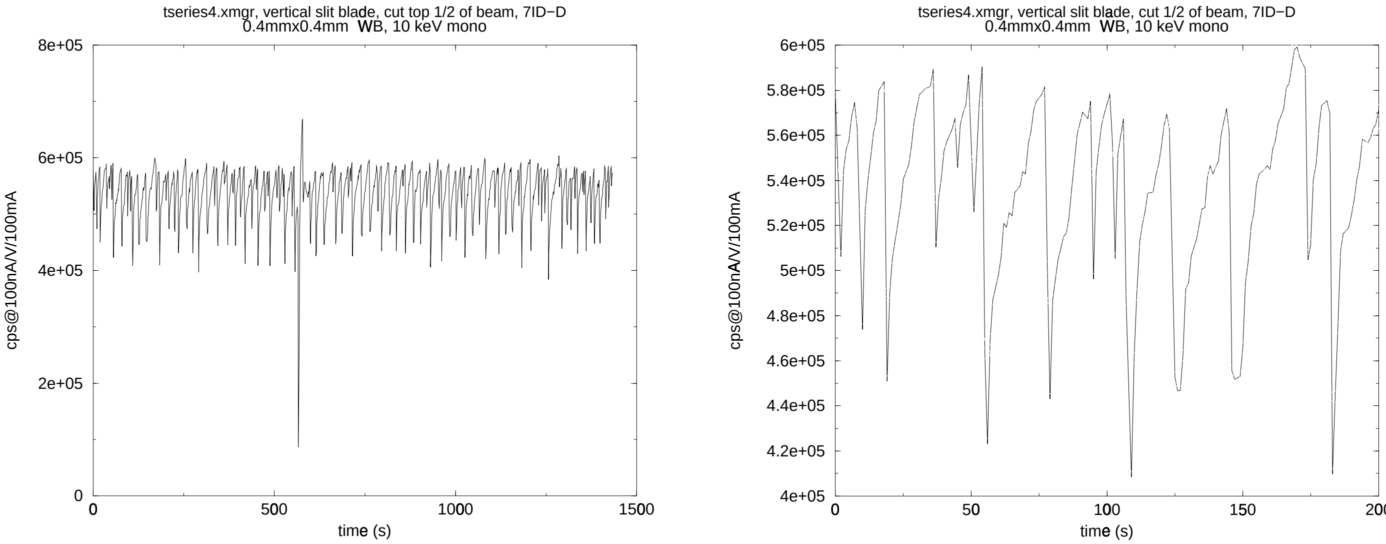

FIG. 4. Time series, top half of the beam blocked. The first two hundred seconds are expanded on the RHS figure.

To estimate if beam motion also occurs, we cut the beam intensity in half, using an horizontal edge, blocking the top half of the beam. Fig. 4 shows much larger fluctuations, with 8.3 % fluctuations rms, and 21 % fluctuations peak to peak. The RHS plot in Fig. 4 expands the first 200 seconds of the time series to show the shape of the time fluctuations. One observes a fast decay followed by a slow relaxation typically, reminiscent of the pressure fluctuations of the closed loop.

The pressure on the cryocooler closed loop is maintained by a resistive heater which is fed by a pressure controller which can self tune its PID parameters using some fuzzy logic routines. The fuzzy logic can be modified through a parameter called DFAC. We tried two values of DFAC=3 and 4, but this did not change the fluctuations amplitude significantly. With DFAC=4, the rms fluctuations were 7.9 %, whereas they were 8.3 % with DFAC=3. During this test, we did find some useful information though. While the fuzzy logic was solving for its new parameters, the pressure dropped from 30 PSI to 28 PSI. With an horizontal blade blocking the top half of the beam, the measured flux went from being half of the total flux to being the whole flux. Once the pressure returned to 30 PSI, the measured flux was again half the total flux. This behavior implies that the beam moved down, clearing the top blade and peaking the flux.

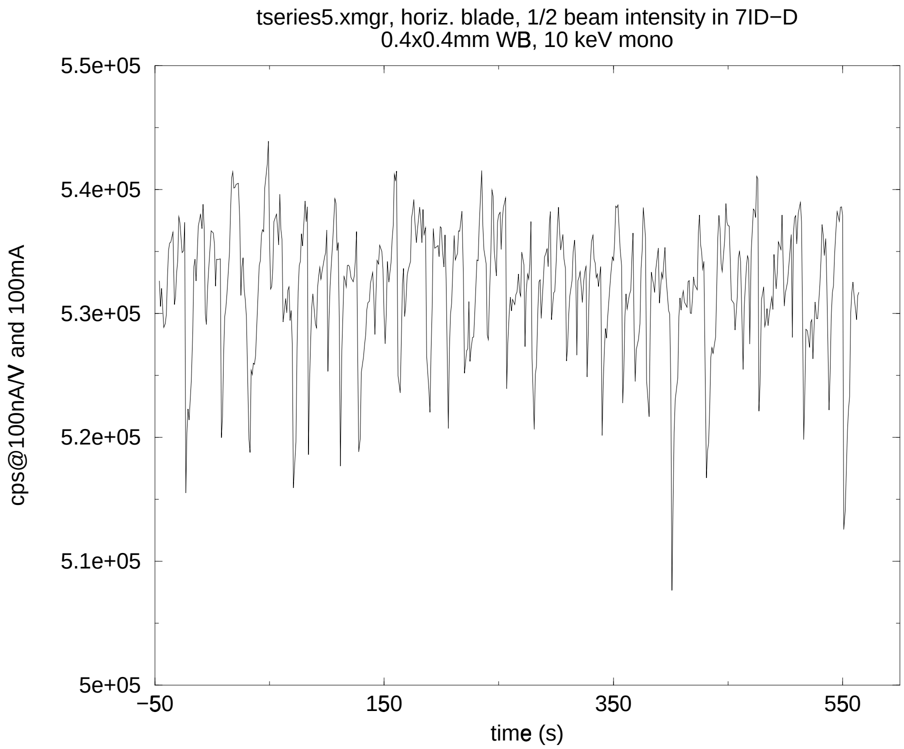

FIG. 5. Time series, inboard half of the beam blocked.

Fig. 5 shows the intensity fluctuations when a vertical blade cuts half the beam, on the source inboard side. The rms fluctuations are 0.97 %rms, or 3.4 % peak to peak, thus slightly larger than those found on the total flux. Clearly the vertical beam motion is much larger than the horizontal one. We will investigate this further by setting a slit off-axis to be more sensitive to the beam motion given that the slope on the beam profile is steeper away from the beam center.

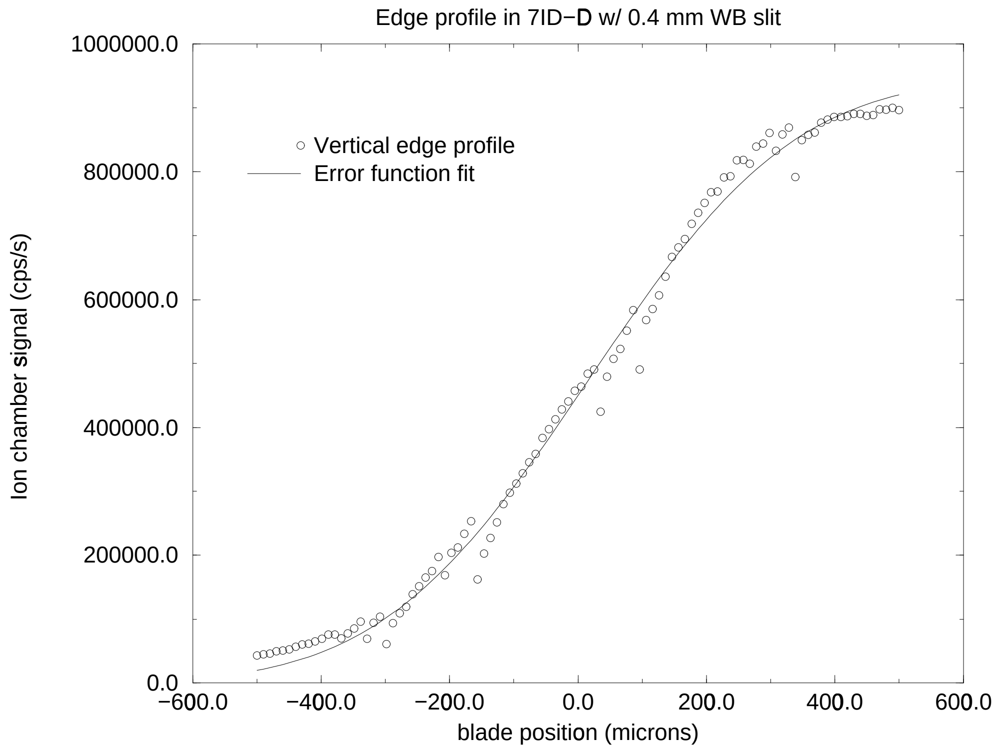

FIG. 6. Vertical beam profile in 7ID-D.

Fig. 6 shows a scan of a vertical blade, with the positive direction being upward. A fit to an error function profile is shown also with a standard deviation of $\sigma = 253.9$ μm. or a FWHM of 597 μm. The measurement is clearly approximate due to the beam fluctuations.

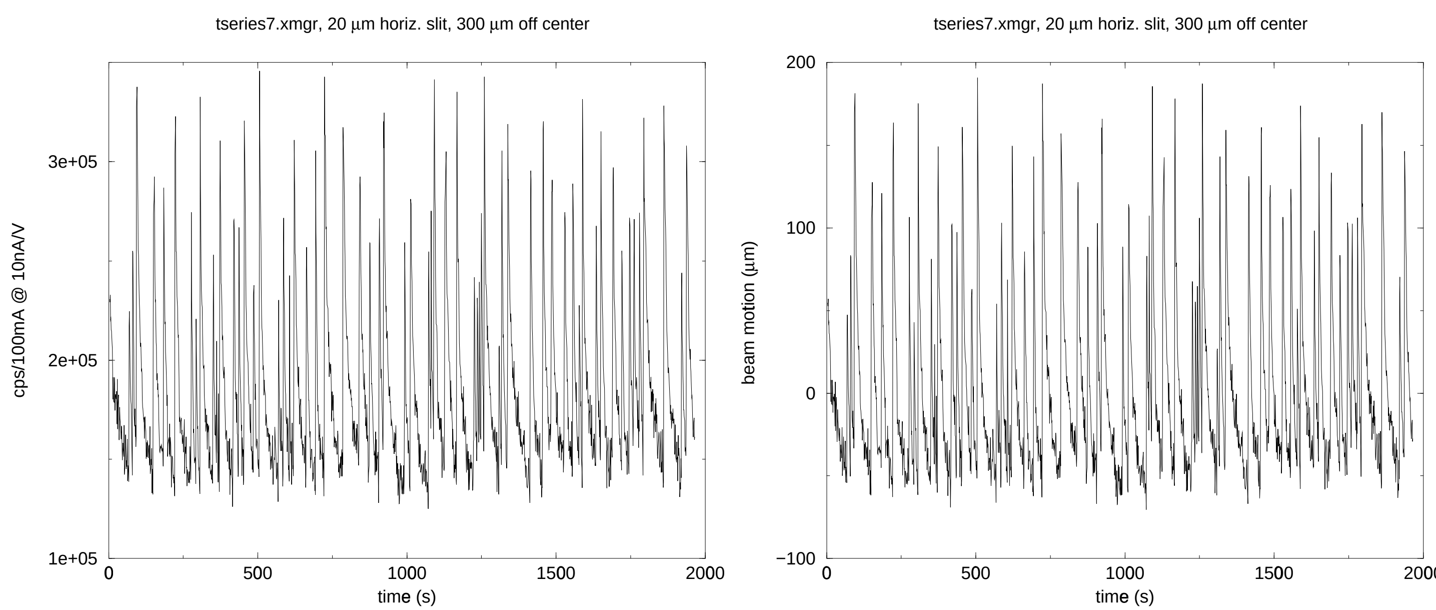

FIG. 7. (left)Time series of the intensity through a 20 μm slit. (right) Estimated beam motion from LHS time serie.

Figure 7 shows the flux through a 20 um horizontal slit off centered vertically on the top portion of the beam by about 300 μm (approx. HWHM). The fluctuations seen here when compared to those found in Fig. 4 are much enhanced due to the enhanced slope at the off-axis position.

Since our aperture is above the center of the beam, a fast motion of the beam up followed by a slow relaxation down explain the intensity profile observed in Fig. 7 and Fig. 4. From the slope of a Gaussian at the half intensity position, we can estimate the beam motion seen. The RHS of Fig. 7 shows the beam motion, after normalizing the intensity to its average, and multiplying by the appropriate slope. The rapid movement up is by about 180 μm, and the whole motion amplitude is about 230 μm.

We also performed a similar analysis with a vertical slit, off-centered horizontally by 310 μm. The beam profile was measured similarly as in Fig. 6. Although not shown, the profile fit nicely an error function, with a standard deviation of 438 μm, thus a FWHM of 1.03 mm. The beam motion deduced from this analysis had an amplitude of 30 μm. In our analysis, we found some inconsistencies in our measurements with an edge blocking half the beam and with an off-axis aperture, thus the beam motion may be overestimated in the horizontal.

To conclude these tests, we also turned off the LN2 flow in the first crystal to test whether the monochromator could be operated in this mode, and whether the 20 second fluctuations would disappear. Since a small (0.4 mm)^2 10 keV white beam deposits only about 6 W of power on the first crystal, one would think that the first crystal could stand such a small heat load without cooling. A quick thermal estimate of the first crystal temperature gradient shows a temperature change of about 22 K [2] between the center of the beam footprint and the fixed cooling bath. So we tested the monochromator with the first crystal at room temperature.

After realignment of the two crystals, we looked at the beam on a video monitor and the beam looked quite stable on short time scales of 1-10 seconds. Unfortunately, the second crystal theta angle had to be realigned every five minutes to keep the flux roughly constant. The total flux was also only about 53 % of the typical flux of the monochromator when cooling is on, which we suspect is due to the larger thermal bump at room temperature [2]. The first crystal temperature rose by 25 K in one hour, thus without cooling, large temperature drifts render the monochromator unusable. Interestingly enough, it took on the order of 10 hours for the monochromator to return to room temperature, so the first crystal is very well insulated from its mounting brackets. Its sits on three ceramic balls. It may be possible to use the monochromator in this mode if the beam size was considerably reduced to say (100 μm)^2 and some coolant was flowing through the first crystal.

III. ANGULAR SHIFT VERSUS FIRST CRYSTAL TILT

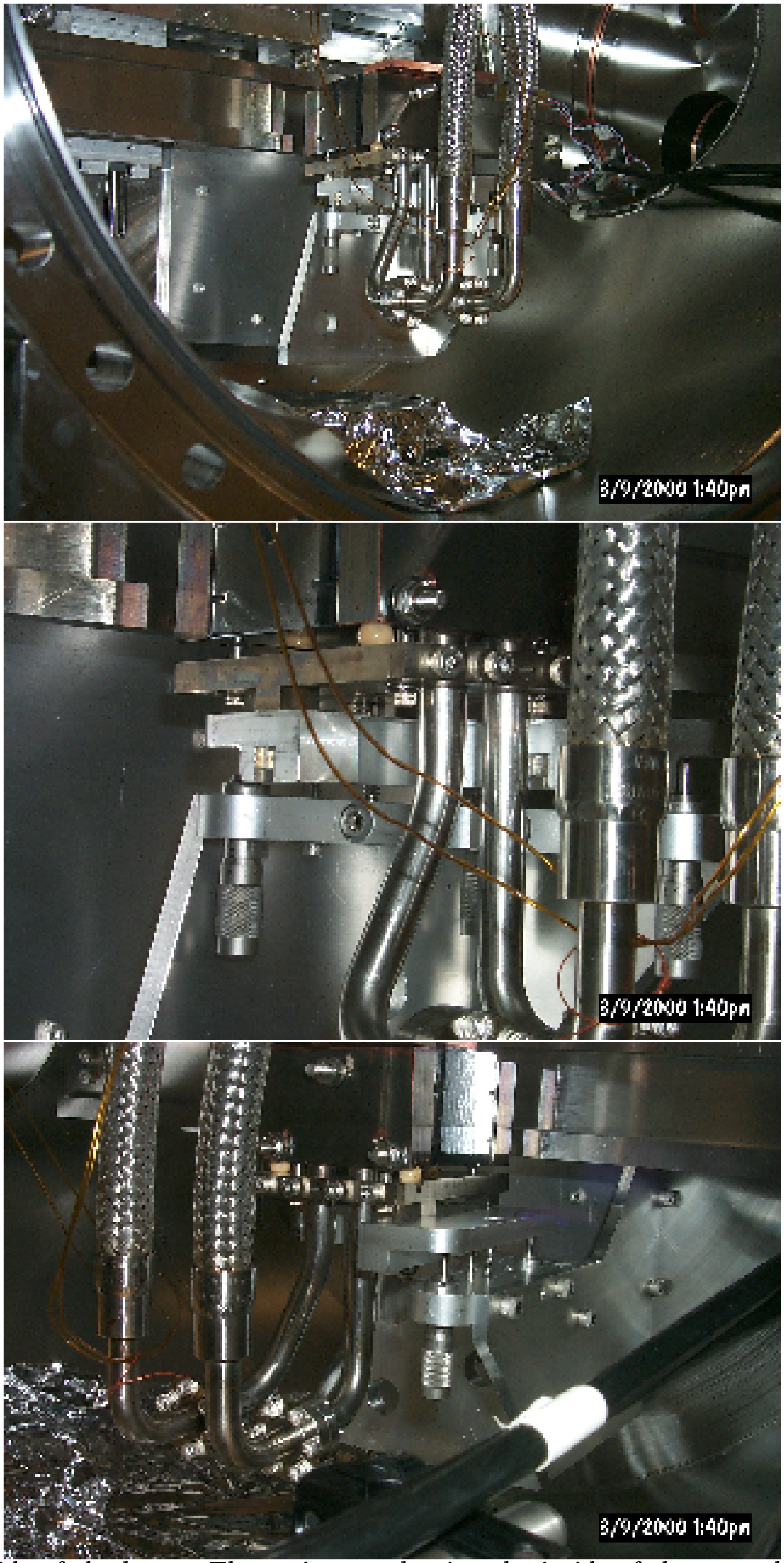

FIG. 8. Inside of the beast: Three pictures showing the inside of the monochromator tank, focussing on the first crystal assembly.

Fig. 8 shows the first crystal mount in detail. The top picture shows the Si (111) block sandwiched by two Invar plate sealed by In seals. The seal is tightened by three screws going through the first crystal. The LN2 flows from the flex lines into the first Invar block and through the Si block. The first crystal sits on the movable half of a modified Newport kinematic mount (see middle picture). The crystal sits kinematically on three ceramic balls and is held firmly by 4 U-joint placed on the four corners of a transition plate with is firmly attached to the modified Newport mount. Springs pull the plate that the crystal sits on down onto the micrometers which adjust the position and orientation of the plate. In addition, there are two screws which can be tightened to firmly hold the top plate against the micrometers once they are adjusted properly. The LN2 lines are directly attached to the transition plate by two screws, but have no other strain relief. The bottom half of the modified Newport mount is attached to a box structure which is fixed to the Huber theta circle.

Following a suggestion from Ernest Williams, we borrowed 2 tilt sensors from ORNL and placed them on top of the first crystal. and on various parts of the first crystal mount. They have the same sensitivity as those for the mirror filter mounts, and it was more convenient to use theirs since ours are wired into the mirror filters. We pressurized the LN2 reservoir with nitrogen gas and measured the resulting tilt in theta and chi of the first crystal. The same sensor found on the cryocooler unit was used to record the applied pressure.

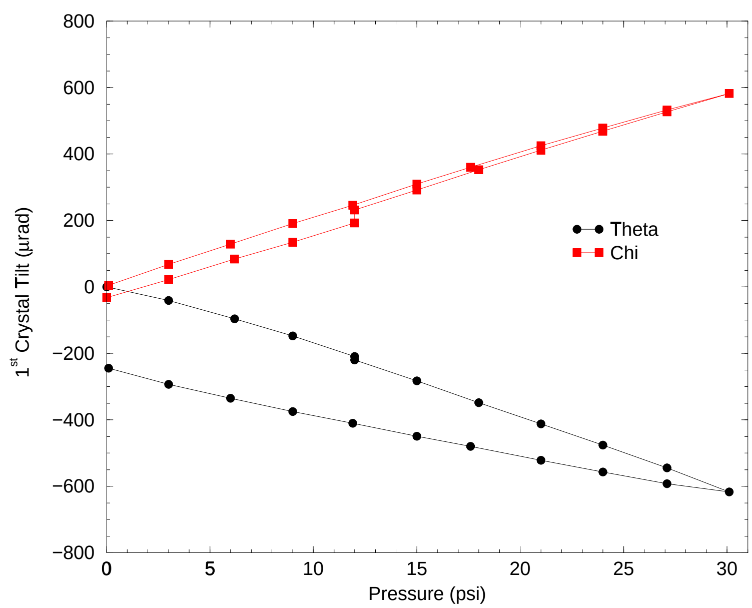

FIG. 9. Tilt angles vs applied pressure.

Fig. 9 shows the tilt sensor angular tilt versus the applied pressure for the theta and chi angle of the monochromator. Typically after a first pressurization and depressurization cycle, the curve were quite reproducible. Hysteresis is present on both axes, but was more pronounced on theta.

Initially, we had forgotten about the two screws that fix the Newport kinematic mount in place, and so our hypothesis had been that the springs alone were insufficient to prevent the crystal from moving in response to the LN2 feed lines flexing during pressure changes. But, there are those two screws. However, one of them was completely loose. So we said:

Aha! We thought that was the culprit. But, when we tightened that screw up so that both screws were pulling down, we observe the EXACT SAME tilt versus pressure. The punch line is that we measure a reproducible, linear dependence of both theta and chi on pressure. For theta, the variation is 425 microradians change in tilt from 0 to 30 psi and for chi, 621 microradian change in tilt from 0 to 30 psi. The change in pressure during the regulator cycle when the cryocooler is running is about 0.3 psi, producing a 4 microradian change in theta, thus 8 μrad in two theta. This is moderate relative to the Darwin width, but produces a 240 μm vertical beam translation 30 meters downstream. During an automatic fill of the LN2 reservoir the pressure typically changes by about 2 psi over the course of about 10 minutes, during which the x-ray intensity vanishes. 2 psi produces a change in theta of 27 microradians, well outside the Darwin half-width of about 15 microradians. Hence, we lose the beam. So, the tilt-vs-pressure measurements are completely consistent with our earlier observations on the x-ray beam. More details of our pressurization tests are available in hypertext at

`http://www.umich.edu/~dufresne/mhatt/mono.html`

. This link will show where much of the flex occur on the first crystal mount.

Note also that in May 2000, we tested the effect of pressurization of the second crystal. We found no measurable angular shift to a 20 PSI pressurization. After reinstalling a new crystal in the monochromator tank, we repeated the pressurization tests with tiltsensors. This new crystal was assembled slightly more stiffly, so now a **20 psi change causes a 200 μrad tilt in theta**.

It may be possible to use feedback to stabilize the HHL x-ray beam via the piezo translator on the second crystal. Ernest has already connected up an EPICS VME D/A to the input of the driver for the piezo and knows of PID sequence record software which could be used to take any signal input to EPICS to close the loop with the piezo. We plan in future tests to feedback on beam position provided by a X-ray beam position monitor that we built following a design of Randy Alkire from SBC-CAT [3]. However, as our results above indicate, it is not so obvious that second crystal feedback would solve the problem. It MAY be important for subtle effects, but right now our task is to remove the gross mechanical sensitivity to pressure changes.

ACKNOWLEDGMENTS

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